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Users Manual for *Camera Calibrator V1.5*

This manual comprises three main sections along with two appendices:

PART A - Quick Reference:

A listing and brief description of all *Camera Calibrator* menus, toolbar buttons, cursors and hotkey functions.

PART B – Software overview:

An explanation of how *Camera Calibrator* performs camera calibration from digital images, with details about the various functions and features of the software.

PART C – Recommended operating procedures:

How to set up the coded targets and capture suitable imagery for camera calibration.

APPENDIX 1 – Camera *Calibrator* installation note.

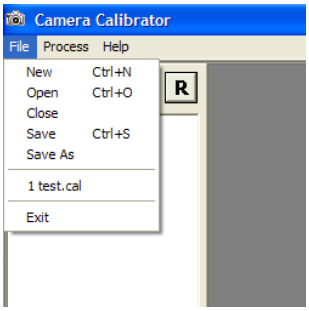
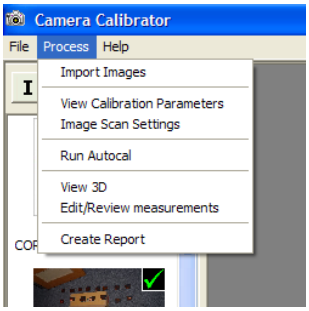
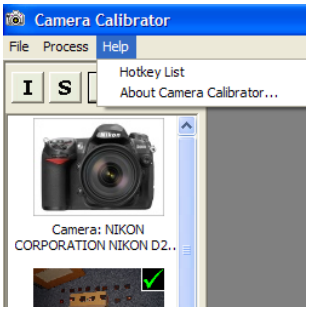
APPENDIX 2 – The End-User License Agreement.

PART A Quick Reference

Provided here is a quick reference to the *Camera Calibrator* menus, toolbar buttons, cursors, hotkeys, as well as image and 3D view functions. A detailed explanation of how to use the software is presented in Part B.

A1. Main screen - menus and toolbar Buttons

A2. Pull-down menus

FILE MENU	PROCESS MENU	HELP MENU
		
- New project - Open project - Close project - Save project - Save project (under another name) - Most recent *Camera Calibrator* projects - Exit program	- Import images (for calibration) - View camera calibration parameters - Access image scan settings for automatic calibration - Run the automatic camera calibration - View the results in 3D** - Edit/Review image measurements** - Create a PDF report**	- List of hotkeys - About

** - *These options are available after camera calibration has been performed.*

A3. Toolbar buttons

- Import images for camera calibration.

- Access image scan settings (for open image or first image).

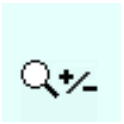
- Perform automatic camera calibration.

- View results in 3D

- View summary of results and create PDF report

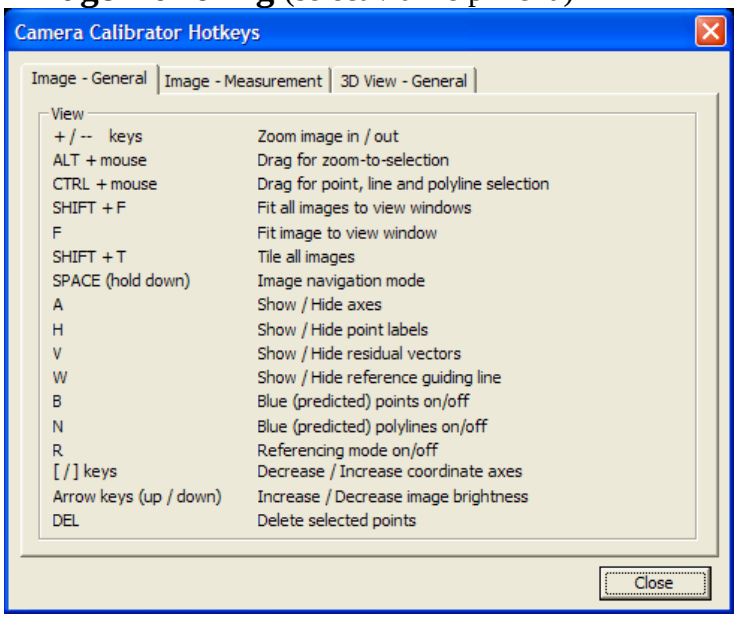
A4. Cursors

- **Select Cursor**: used for 'select' functions such as highlighting, marquee dragging, etc. Default cursor, or invoked via the **Ctrl key**.

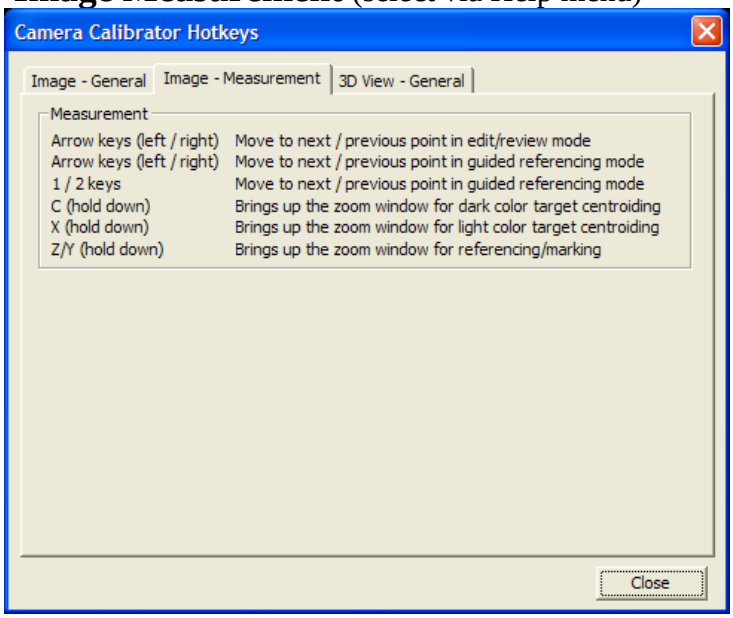

- **Navigate Cursor**: used for zooming in/out or panning within an image (left click & drag); invoked via the keyboard **Space Bar**.

- Cursor for point marking/positional adjustment in **Edit/Review Mode**. Tip of blue pencil is used to mark or move feature point in an image. Not required for fully automatic measurement (targets are centroided and should not be moved)

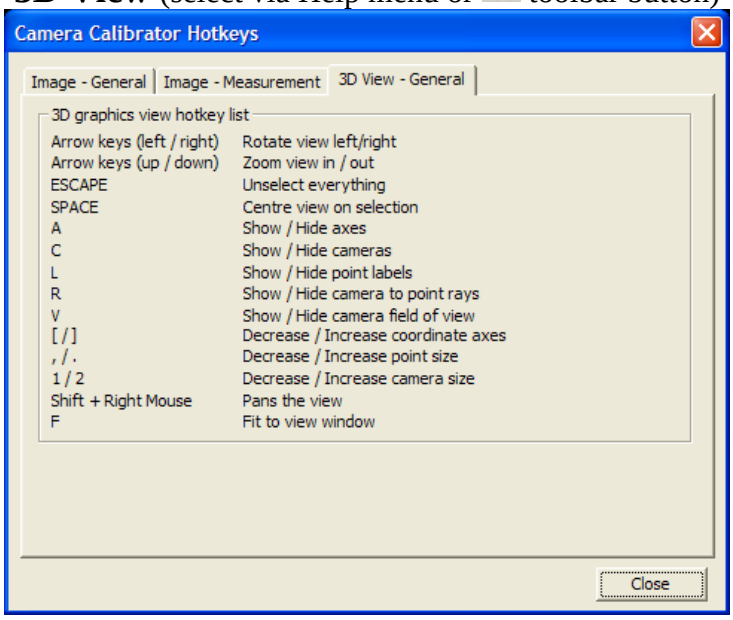
A5. Hotkeys for Image Handling (select via Help menu)



A6. Hotkeys for Image Measurement (select via Help menu)


Camera Calibrator Hotkeys
Image - General
Image - Measurement
3D View - General
Measurement
Arrow keys (left / right) Move to next / previous point in edit/review mode
Arrow keys (left / right) Move to next / previous point in guided referencing mode
1 / 2 keys Move to next / previous point in guided referencing mode
C (hold down) Brings up the zoom window for dark color target centroiding
X (hold down) Brings up the zoom window for light color target centroiding
Z/Y (hold down) Brings up the zoom window for referencing/marking
Close

A7. Hotkeys for 3D View (select via Help menu or toolbar button)


Camera Calibrator Hotkeys
Image - General
Image - Measurement
3D View - General
3D graphics view hotkey list
Arrow keys (left / right) Rotate view left/right
Arrow keys (up / down) Zoom view in / out
ESCAPE Unselect everything
SPACE Centre view on selection
A Show / Hide axes
C Show / Hide cameras
L Show / Hide point labels
R Show / Hide camera to point rays
V Show / Hide camera field of view
[/] Decrease / Increase coordinate axes
, / . Decrease / Increase point size
1 / 2 Decrease / Increase camera size
Shift + Right Mouse Pans the view
F Fit to view window
Close

A8. Zooming/Panning in an Image

The four zoom options available in the active image window are:

- The wheel of the mouse can be used to zoom in and out.
- The **Z** (or **Y**) key. When the pencil cursor is over the point of interest, hold down the Z key to generate a zoom window. The cursor can then be accurately placed on the feature point of interest. The window will remain open as long as the Z (or Y) key is held down.
- The **ALT** zoom. Press the ALT key and use the left mouse button to draw a marquee box that will enclose the enlarged portion of the image. The image will be zoomed upon release of the mouse button.

- The ‘+’ keyboard key to enlarge the image and the ‘-’ key to reduce it.

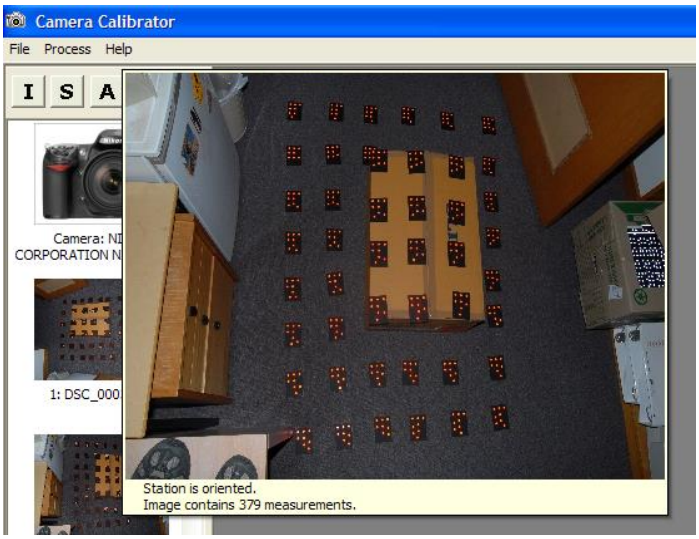
To ‘pan’ or roam within an enlarged (zoomed-in) image, hold down the wheel of the mouse and move the mouse. The slider bars can also be used for this function, as can dragging the mouse with left-button held down in Navigate mode (accessed by holding down the space bar).

A9. 3D View Functions

- To zoom in or out within the 3D view (make sure the cursor is over the window), the wheel of the mouse can be used.
- To rotate the 3D View about the axis coming out of the screen, hold down the CTRL key and the right mouse button and move the mouse.
- To pan in the 3D View, hold the SHIFT key and the right mouse button and move the mouse.
- To bring a point to the centre of the 3D View display window, first highlight the point (left mouse button and drag) and then hit the space bar.
- Moving the mouse with the right button pressed, and the point mentioned in the previous dot-point still highlighted, rotates the display about the highlighted point. Also, the rotations described in the second dot-point will be about the highlighted point.
- To centre the network in the 3D View, use the F key.
- An Image can be opened from the 3D View by double clicking the corresponding camera

A10. Tool-tip Display for Image Thumbnails

By hovering the mouse cursor over image thumbnails, an enlarged version of the image is shown.



PART B Software Overview

B1. Introduction to Camera Calibration

Photogrammetric measurement is both accurate and reliable, but in order to realize maximum accuracy, the camera or cameras employed must be calibrated. A full explanation of the motive behind camera calibration is given in **Fraser, C.S., 1997. "Digital Camera Self-Calibration".** ***ISPRS International Journal of Photogrammetry and Remote Sensing*****, Vol. 52, pp. 149-159**.

This paper is online: http://www.photometrix.com.au/ Digital_Camera_Self_Calibration.pdf

A brief description of each of the 10 parameters of camera calibration is now given.

Focal Length (c) and Principal Point (x_p & y_p)

This focal length and the principal point offsets indicate how far the optical axis of the lens is displaced from the centre of the image formal. The 'focal length' actually refers to the Principal Distance, which changes with focusing. The nominal lens focal length usually relates to infinity focus. Also, with zoom cameras, this focal length value can vary dramatically, but *Camera Calibrator* seeks one value for the camera used in the survey. This is why it is important not to change zoom or focus during the photographic session. Generally x_p & y_p are close to zero (e.g. 0.5mm or less).

Radial Distortion (K_1, K_2 & K_3)

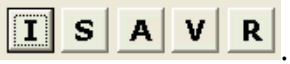
The three parameters K_1, K_2 & K_3 describe the radial lens distortion of the camera lens. Radial distortion can reach significant levels in digital camera lenses and it needs to be corrected when computing 3D feature point position to even modest accuracy levels. Radial distortion also varies with focusing which is a further reason not to alter focus or zoom within a measurement network.

Decentering Distortion (P_1 & P_2)

The parameters P_1 & P_2 express the effect of the decentering of optical elements within the lens assembly. This error source is generally quite small and can typically be ignored in all but very high accuracy applications.

Linear Distortion (B_1 & B_2)

These parameters, B_1 & B_2, effectively model any relative error in the specified pixel size. Thus, they can usually be set 'fixed' to zero and ignored.

After capturing imagery for calibration (discussed in Part C), there are five main steps to operating the *Camera Calibrator* software. Each step has one tool bar button, and each should be completed in order. 

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B2. Importing Project Images & Associated Camera options

When commencing a new *Camera Calibrator* project, press the button on the toolbar. Alternatively select **Process | Import Images** from the pull down menu. This initiates a dialog for the importing of images into the project. This procedure should be followed:

- The 'Image Browser' dialog for importing images will appear (see below). Select the folder that contains the images. An image in the Select Image(s) list is transferred into the project by first highlighting the image or images and then selecting the '>' button. The '>>' button moves all images into the project. Similarly, the '<' button moves highlighted images out of the project list, and '<<' removes all images.

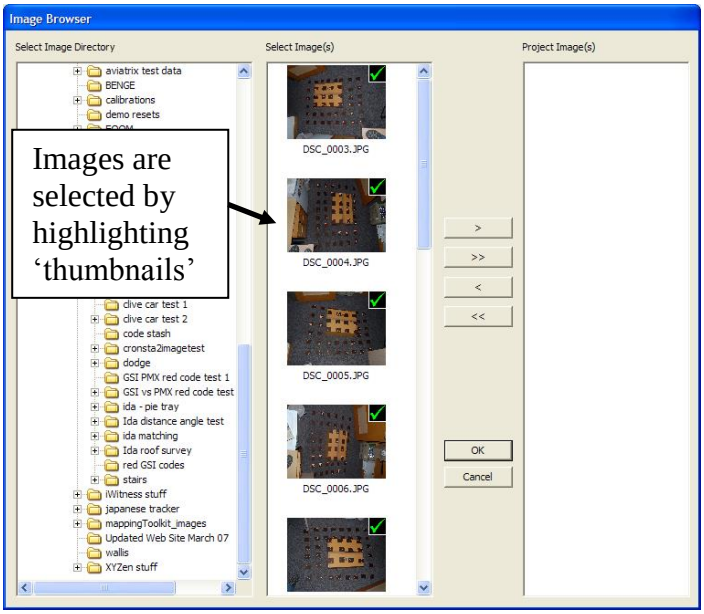


Figure B3

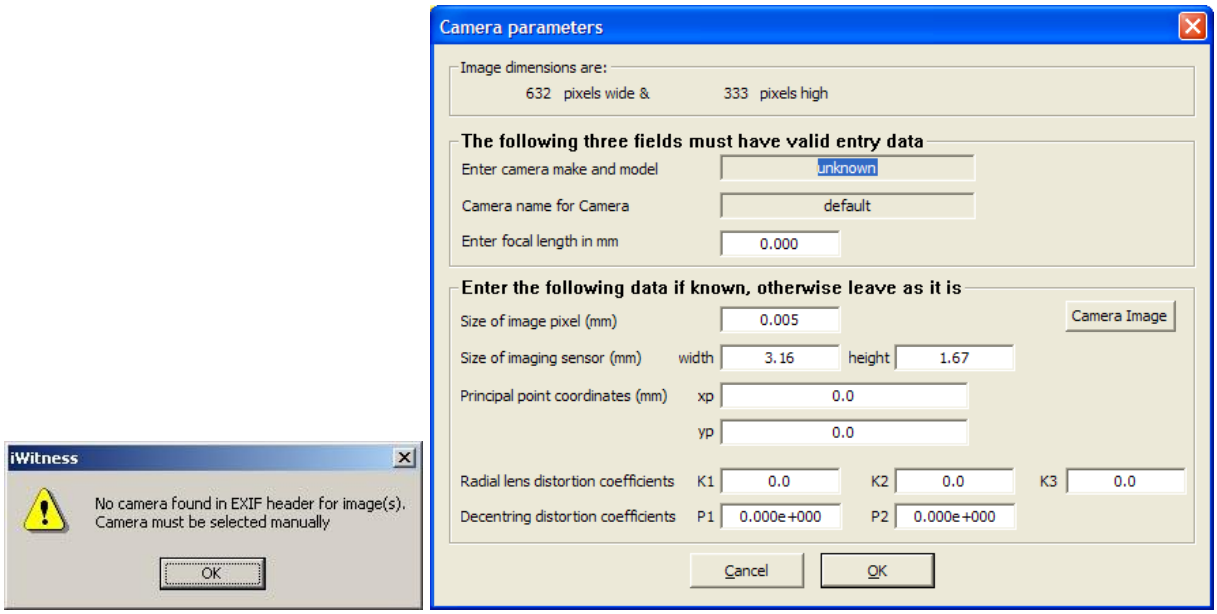
- A single image at a time can be selected, or multiple images can be highlighted by using the mouse and dragging. Holding down the SHIFT key means all images between two selected images will be highlighted, and the '>' button can then be used.
- Press OK when all the appropriate images have been selected for importing into the project (i.e. they appear in the right-hand-side list).

An up-to-date list of most digital cameras and their key metric design characteristics is provided with the *Camera Calibrator* software. From time-to-time, an updated version of this database is made available for download from:
http://www.photometrix.com.au/downloads/globalcameras.dat
Simply download & save this file, then replace the globalcameras.dat for the *Camera Calibrator* (in the 'cameras' subdirectory, underneath where the 'CameraCalibrator.exe' file is installed).

Camera Calibrator supports JPEG (*.jpg) images which are suitable for calibration. When JPEG images are imported into the project, the program automatically reads the camera type from the 'exif' file header. Thus, the operator does not have to identify the camera or cameras used in the project.

If the image files do not contain information which identifies the camera(s), a warning message is displayed, as indicated below. This means that before the importing of images into the project, camera data must be entered either manually. A valid (non-zero) entry must be made for the focal length, but it need only be a rough estimate of the true value. The image pixel size (mm) is the only critical value that must be entered. Entering the wrong pixel size introduces a scaling effect, which is compensated by the computed focal length. Unknown image pixel sizes can be calculated as a function of the physical CCD dimension and image resolution.
See http://www.photometrix.com.au/images/CCD_sensor_sizes.gif

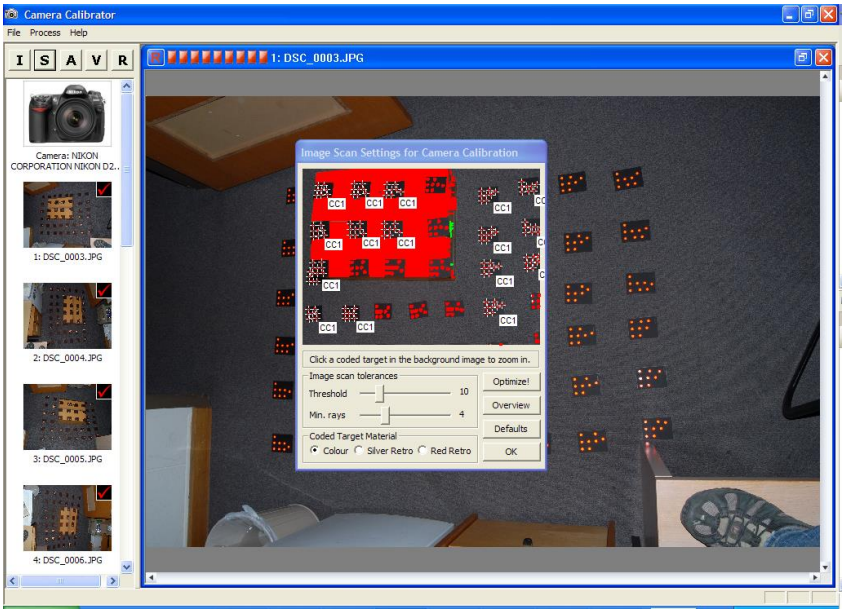
The default pixel size is set to 0.005mm. A typical range for consumer digital cameras is 0.002mm to 0.009mm, and it is desirable – though not mandatory – to enter the correct value here if it is known. Adoption of the default pixel size will lead to satisfactory camera calibration results. Once the required entries are made, click OK to save the camera data. This camera will then be added to the camera database, so it is available next time.



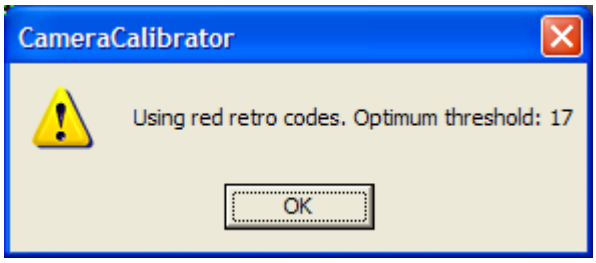
The camera calibration parameters of focal length, principal point offset and lens distortion vary with focus and zoom settings for a lens. The possibility arises that multiple sets of calibration data might be needed if the camera is employed either at different lens focus, or with different lenses or zoom settings, or if different examples of the same camera model are to be calibrated. This can create difficulties because the same camera name, etc. will be read from the EXIF header in the images, but the essential calibration data, which may or may not be known for the particular lens and focus, will be different to that stored for that camera in the database. *Camera Calibrator* overcomes this problem by assigning 'unique identifiers' (Unique IDs) to given camera/lens/focus combinations. The procedure for assigning a Unique ID, which is essentially a new entry for an existing camera in the database, is simply to type the Unique ID in to the Camera Parameters dialog, which is opened by double-clicking on the Project Camera icon, then press OK.

B3. Image Scan Settings

Part two of the five-part process to automatic camera calibration in *Camera Calibrator* involves setting up the appropriate image scan settings, so that the software can automatically identify and measure the coded targets in each image. Press the button on the toolbar. Alternatively select **Process | Image Scan Settings** from the pull down menu. This opens the first image in the project (or is bound to the currently open image) and initiates the image scan settings dialog, as below.



At this stage, *Camera Calibrator* has an option to automatically detect the type of coded targets used, and to adjust the scan settings accordingly. Simply press the 'Optimize!' button and wait a few moments while the software processes the image, then a message will appear, for example:

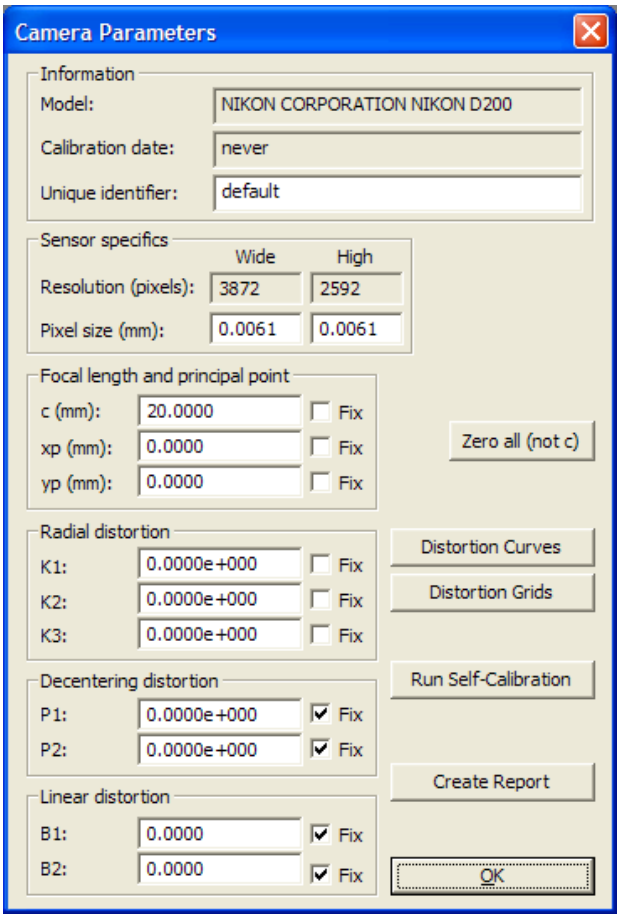


If these settings are appropriate, press OK and go on to B4. If not, the settings can be adjusted manually, by choosing a pixel brightness threshold (typically about 10 is a good value, to separate the target dot from the background); minimum number of rays for each point to be deemed value (typically 4 is a good value); and the type of coded target material used. By left-clicking on a coded target in the image, the current settings will be applied to the image-chip in the dialog, giving an indication as to whether they would be acceptable for the overall process. Click 'Overview' to zoom the image-chip out and operate on a large portion of the image. Once the scan settings have been selected, press OK.

B4. Automatic Camera Calibration (Autocal)

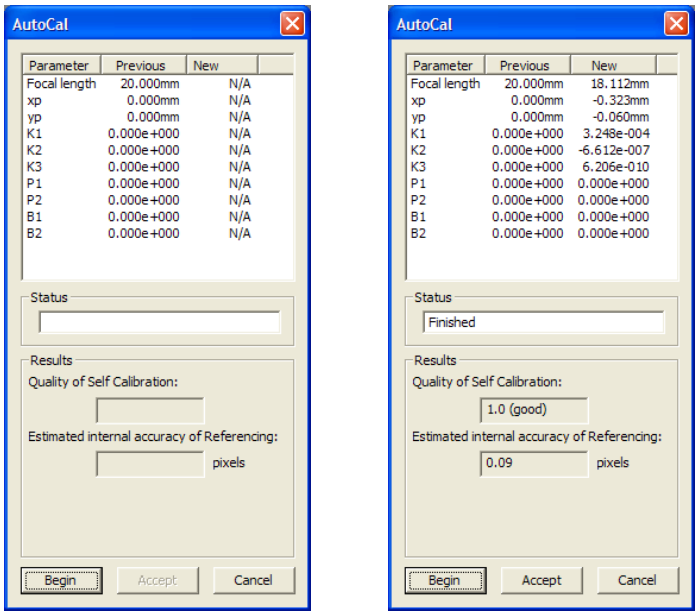
Once the image scan settings have been selected, *Camera Calibrator* has enough information to perform the calibration.

A list of the initial camera parameters can be generated in the main window by double-clicking on the camera icon (see below). Caution must be exercised in altering camera calibration values. If nothing is known of these, other than the approximate focal length value (which must always be entered), the lens distortion parameters K_1, K_2, K_3, P_1, P_2, B_1 & B_2 should be left at either their previously calibrated values, or at zero. The latter four values will rarely be other than zero (and fixed) for all practical purposes as indicated below.



By default in *Camera Calibrator*, the settings B_1, B_2, P_1 & P_2 are zero and fixed which locks the value to zero in any calibration. Except in the cases of either prior comprehensive calibration or in extremely strong network geometries designed for high accuracy measurement, these parameters can generally be left at zero and fixed, or at their 'calibrated values' from the comprehensive camera calibration process. In cases where the highest possible accuracy is sought for both the calibration and subsequent 3D measurements, un-tick the boxes for P_1 & P_2 before running a calibration. This action, however, will rarely lead to significant accuracy improvements. Also B_1 & B_2 can be un-ticked, but this should only be contemplated in the very rare cases where it is known that the digital camera has rectangular pixels. Click OK.

The automatic calibration procedure can now be run. Select the button on the toolbar. Alternatively select **Process | Run Autocal** from the pull down menu. If the images have already been scanned, click 'Run Self-Calibration'. A warning message may be presented for example if there is no roll-angle diversity in the camera station network, which means that all images in the network considered were recorded in 'landscape' mode (i.e. normal camera rotation, as indicated by the small 'buttons' on the camera icons in the 3D view). Self-calibration ideally needs at least one 'rolled' image. The following dialog (below left) will be presented, where the process is initiated by pressing 'Begin'.

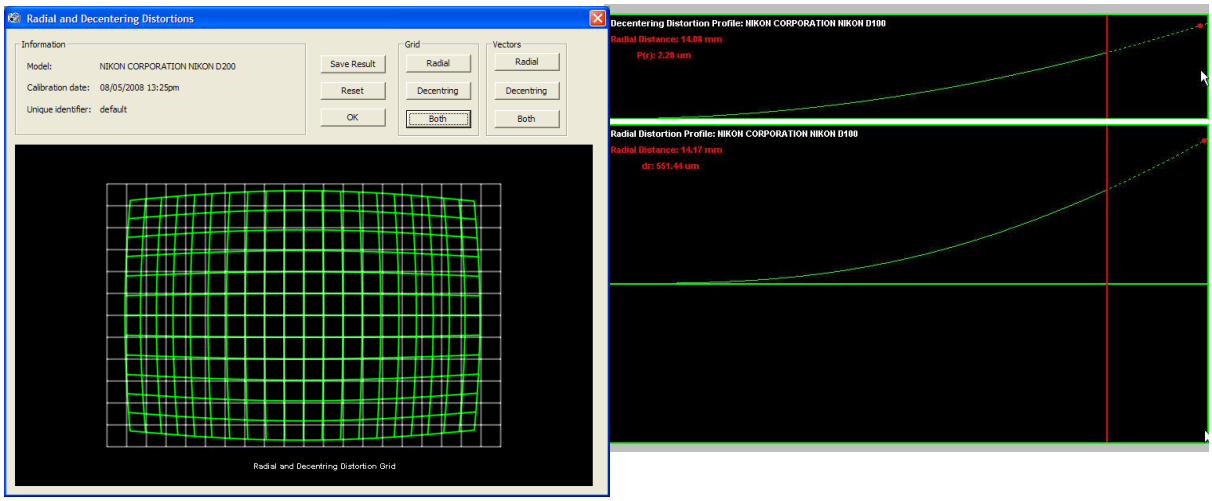


After pressing 'Begin', *Camera Calibrator* will open and scan each image one-by-one, then perform the automatic camera calibration routine and display the results in the same dialog, as above (right). This process may take several minutes to complete, after which the calibration is complete. Press 'Accept', and then analyse the results.

B5. Results

The outcome of the automatic calibration routine performed by *Camera Calibrator* is the generation of new camera parameters, as shown in above (right), where the new calibration data is listed alongside the old. Measures of a successful camera self-calibration can be seen in the 'Quality of Self-Calibration' field, where an accuracy value along with an indicator of the calibration quality (good, average or poor) is shown. The 'Estimated accuracy of referencing' value should always be 0.5 pixels or smaller, with a commonly encountered value being around 0.1-0.25 for off-the-shelf consumer digital cameras.

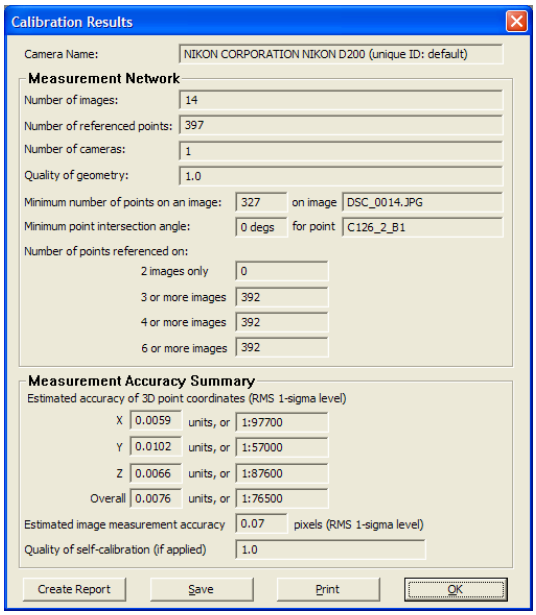
Radial and decentering distortion curves and grids can be plotted by choosing 'Distortion Curves' / 'Distortion Grids' in the camera parameters dialog. Example results are shown below:



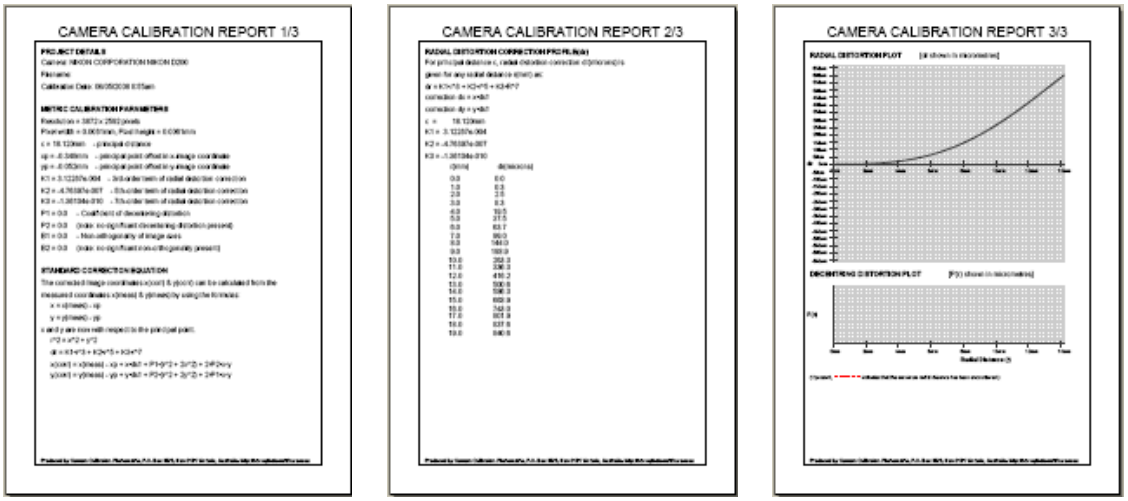
By far the easiest way to verify the results of a calibration is to view the resulting photogrammetric network in 3D. Any mistakes will be obvious, for example if the points in the network do not logically represent the calibration measurement scene. Select the V button on the toolbar. Alternatively select **Process | View 3D** from the pull down menu. This will open the 3D view. Controls for the 3D view are explained in Part A.

B6. R Summary of Results and PDF Report Creation

Another handy tool to verify the success of the calibration is to view a summary of results. Select the R button on the toolbar. Alternatively select **Process | Create Report** from the pull down menu. The following dialog will appear:


Calibration Results
Camera Name: NIKON CORPORATION NIKON D200 (unique ID: default)
Measurement Network
Number of images: 14
Number of referenced points: 397
Number of cameras: 1
Quality of geometry: 1.0
Minimum number of points on an image: 327 on image DSC_0014.JPG
Minimum point intersection angle: 0 degs for point C126_2_B1
Number of points referenced on:
2 images only 0
3 or more images 392
4 or more images 392
6 or more images 392
Measurement Accuracy Summary
Estimated accuracy of 3D point coordinates (RMS 1-sigma level)
X 0.0059 units, or 1:97700
Y 0.0102 units, or 1:57000
Z 0.0066 units, or 1:87600
Overall 0.0076 units, or 1:76500
Estimated image measurement accuracy 0.07 pixels (RMS 1-sigma level)
Quality of self-calibration (if applied) 1.0
Create Report
Save
Print
OK

The information presented in this dialog is self-explanatory (or already explained). Press ‘Create Report’ to export the results in structured 3-page .PDF format, ready for distribution or filing.



PART C – Recommended operating procedures:

C1. Basic Photography Rules

There are four basic rules which apply to recording images for photogrammetric camera calibration with *Camera Calibrator*:

- The camera lens should not be refocused during the photography session;
- The lens zoom should not be adjusted during the photography session;
- If the camera has an 'auto rotate' function, which digitally rotates the recorded image, the function **must be turned OFF**;
- The imagery should be captured on the highest possible resolution (i.e. image size) and highest quality. For example, a 10 megapixel camera should record 10 megapixel images at the highest quality JPEG setting.

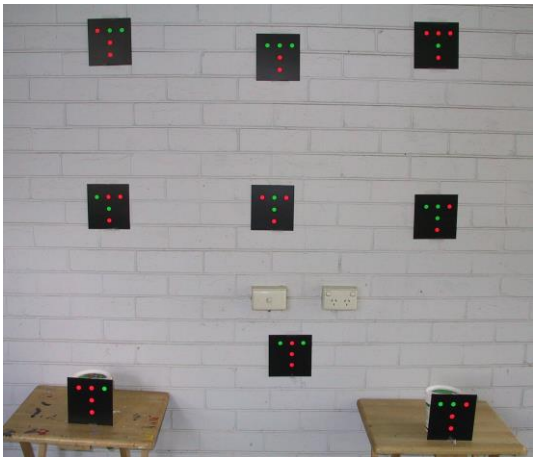
If retro-reflective targets are to be used, the camera will obviously require a flash. If the flash is too bright & its intensity cannot be controlled, sometimes taping a small piece of paper over the flash will have the desired effect (or double-thickness paper, etc).

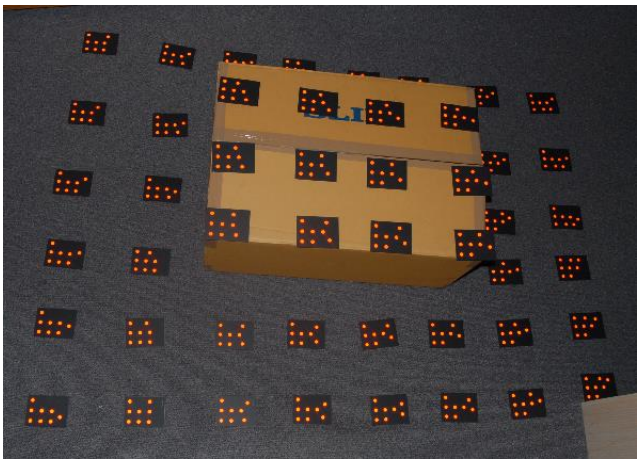
C2. Camera Setup and Target Layout for Automatic Camera Calibration

The fully automatic camera calibration procedure using *Camera Calibrator* employs coded targets and self-calibration. A set of coded targets is provided with the software license. In order to carry out the automatic camera calibration via *Camera Calibrator*, the user requires only:

- A set of at least 12 different coded targets (also called 'codes').
- A space of about 3 x 3m on which to position the codes. This will form the target range, which will be photographed from a camera-to-object distance of from, say, 3-6m, depending on the lens focal length and field of view. It is desirable to incorporate some

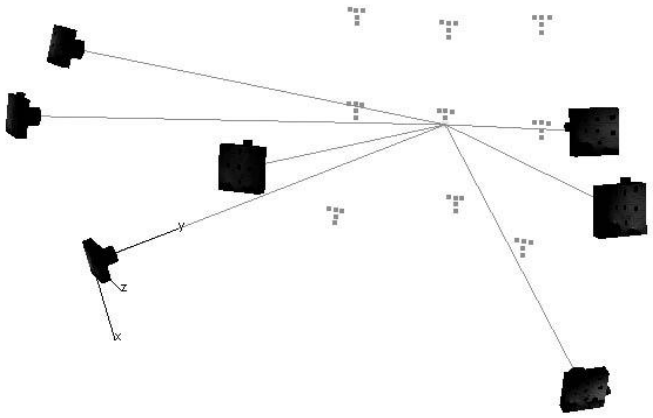
3D distribution within the target point array, so all points do not lie in a perfect plane. Two examples are shown below; one using the wall and one using the floor.





In setting up the target field, keep in mind the following:

- *Shape of the target array.* It is preferable for the target field to have 'depth', for example one or more of the 12 coded targets being out of the plane by 10-20 cm or more. A target array with some 3D distribution is better than a planar array.
- *The camera-to-object distance*. The size of the target field will depend upon the distance from which images are to be taken. To determine this, first set the camera at the focus and zoom setting that you intend to use for subsequent photogrammetric measurement, as it is critical to calibrate the camera at the same zoom/focus that will be normally be employed. Typically, the focus will be set to infinity and the zoom at one of its 'hard stops', usually zoomed fully out (widest field of view). Once these settings are made the operator can balance the requirements of imaging distance versus target field dimensions. Note that in determining the distance, the sharpness of focus in the images is not of great importance. An accurate calibration can be performed with slightly defocused images, which might arise from the camera being set to infinity focus but then being used over a distance of only 3m or so.
- Both target array stability and fixed focus are very important. The targets are not allowed to move at all. If the camera has a manual focus or focus lock, it is very useful to set this and then leave it set for the subsequent 3D measurement projects. Also, attention needs to be given to lighting, with well-exposed images displaying optimal colour saturation or underexposure being required, depending on the coded target material being used.
- An ideal image network geometry for camera calibration is shown below. The convergence angle (horizontal) between the outer two rays should be 70˚ to 100˚ (it is also very desirable to have such convergence in both directions).
- Note the use of orthogonal roll angles for the camera; three images are in 'landscape' orientation, and three in 'portrait'. It is absolutely critical that this 90˚ variation of roll angle is present. It is not important which images are rolled 90˚, but several should be.



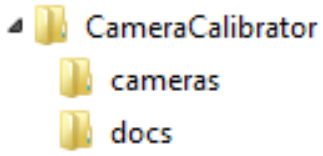
C3. Other recommendations

Camera calibration should be performed periodically using *Camera Calibrator*, say every few months for normal digital cameras, or more often if the camera is accidentally dropped or it is used in a relatively rough environment.

Appendix 1: *Camera Calibrator* Installation Note

The default installation of the *Camera Calibrator* executable, camera database files and documentation will be to the folder **C:\Program Files\CameraCalibrator**.

In C: Program Files (x86)\CameraCalibrator there will be two folders, as shown:



Cameras: This holds the camera information and associated image chips of cameras within the database. You will not need to access this folder (unless updating the globalcameras.dat).

Docs: This holds the Users Manual

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